FINDING THE FAULT INCEPTION TIME USING WAVELET TRANSFORM

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Abstract: This paper deals with the transient detection method utilizing the wavelet transform, which proved to be more suitable for this purpose than the Fourier transform. The aim of this work is to analyze data, obtained from the power network model created in PSCAD software, and to determine the time of the fault inception. This calculated time is then compared with the actual fault inception time set in the model. The results show that the wavelet analysis can successfully detect all tested faults.

Keywords: wavelet transform, transient analysis, travelling waves

1 INTRODUCTION

Frequency components of a signal are usually analyzed using the Fourier transform. This tool is able to decompose a waveform into a sum of sinusoidal functions and provide us a frequency domain representation of the original signal. However, to determine the time when a particular frequency changes, it is necessary to adapt certain modifications. To obtain an information about frequency and time as well, the Short-time Fourier transform (STFT), which segments the analyzed signal, can be applied. The problem of this technique are limitations of the time and frequency resolution. This issue has been solved by developing the wavelet transform.

Wavelet analysis caught the attention of engineers since 1990s [1]. Providing an adjustable time-frequency window that automatically gets narrower when inspecting a high-frequency signal and wider for a low-frequency signal, the ability of this method to analyze a transient is very much improved compared to the STFT. Sudden changes of the signal are usually detected using the maximus modulus or Lipschitz exponent of the wavelet transform. The detailed principle of this method is described in [1].

There are many applications of the wavelet transform. The main are data compression, disturbance signal analysis, noise reduction and fault diagnosis. In this paper, the wavelet analysis is used to calculate the time of a fault occurrence on a transmission line. Many researchers use the wavelet transform to accurately identify and locate a fault in a power system [2]-[6]. Their approaches vary depending on the evaluation methods and the mother wavelets used to decompose the analyzed signal. Usually, the discrete-wavelet transform is adopted to obtain the wavelet analysis detail coefficients, which are then used to locate disturbances present in the signal.

Since one of the problems of current and voltage measurements in a distribution network is that the measurements are not synchronized, a successful transient detection could help with data synchronization. The aim of this work is to apply the wavelet transform to a signal and prove that a transient inception can be precisely detected and therefore potentially used e.g. for synchronizing data.

2 DESCRIPTION OF THE EVALUATION PROCESS

The studied power system was created in PSCAD software. It consists of 110 kV source, 110/23 kV transformer, transmission line with length of 25 km, 23/0,408 kV transformer and 2 MW resistive load, as displayed in Figure 1. The voltages and currents were measured on the secondary side of the 110/23 kV transformer. The transmission line was divided into two parts and functional blocks representing the single-phase-to-ground fault were inserted between them. Time of the fault inception was modified with use of the block called Timed Fault Logic. All measured data (i.e. phase voltages and currents and the earth current) were recorded in a COMTRADE file, which is a format frequently used to capture oscillography of the transient signal.

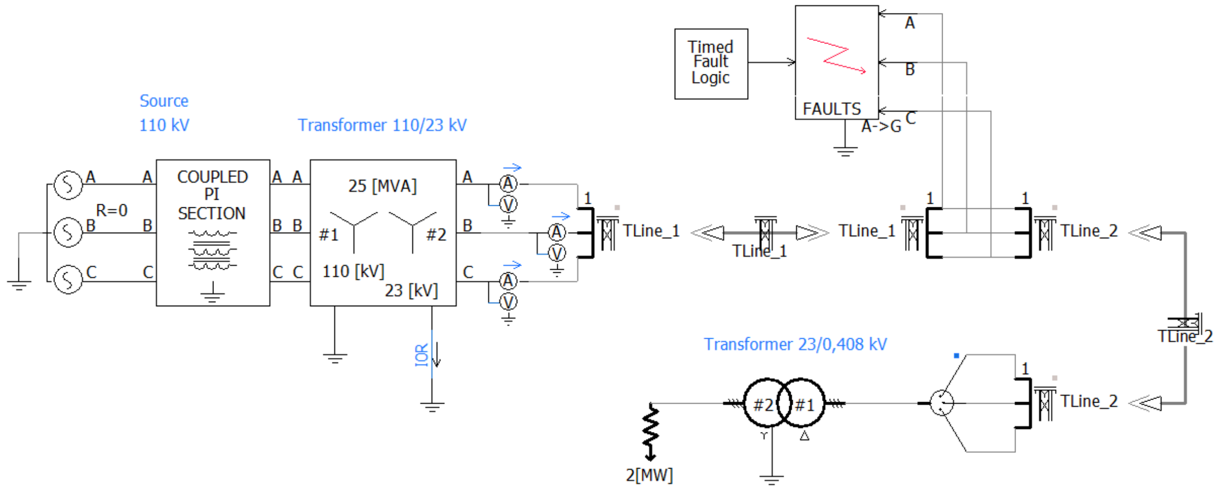

Figure 1: Simulated power system

Parameters of the model components are described in Table 1. The transmission line was simulated using frequency dependent model and its basic configuration is displayed in Figure 2. The soil resistivity was set to 50 Ωm and the fault resistance to 5 Ω.

Source	Voltage U = 110 kV
	Positive-sequence impedance $\overline{Z} = (1{,}98 + 19{,}81)\ \Omega$
	Zero-sequence impedance $\overline{Z}_0 = (1{,}35 + 13{,}48)\ \Omega$
Transformer 110/23 kV	Connection YN/yn
	Power S =25 MVA
	Positive-sequence leakage reactance 11 %
	Eddy current losses 0,06 %
	Copper losses 0,32 %
Transformer 23/0,408 kV	Connection D/yn
	Power S = 0,63 MVA
	Positive-sequence leakage reactance 5,62 %
	Eddy current losses 0,13 %
	Copper losses 1,19 %
Load	2 MW

Table 1: Parameters of the PSCAD model

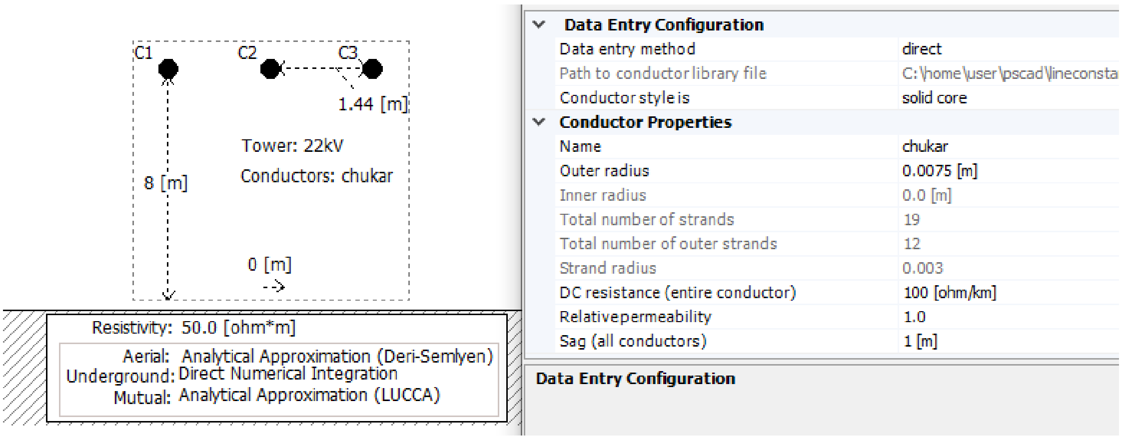

Figure 2: Transmission line model

Regarding the simulation settings, the duration of run was 0,5 s. However, it was not necessary to capture data of the whole simulation. Therefore, only a time window with 0,3 s length that contained the transient was recorded and analyzed. The solution time step was set to 10 µs. This value complies with the minimal time step requirement caused by the chosen transmission line model. When using the frequency dependent line model, the time step needs to be less then one tenth of the shortest travel time of the travelling wave, which depends on the length of the transmission line. In this paper, scenarios with different fault distances were tested. This was achieved by changing the length of the transmission line segments TLine_1 and TLine_2 (Figure 2). Since the shortest tested length was 5 km, the time step had to be less than 16,73 µs.

2.1 DATA PROCESSING

When a fault occurred in the phase A, the data were recorded and stored, as mentioned, in the COMTRADE format. To process this format further, the MATLAB software was used. First, the COMTRADE file had to be converted into a *.mat file. The next step was to choose a variable (or variables) suitable for the wavelet analysis. After the fault occurrence, the transient is observable in all captured data. Still, for the best results, it is convenient to choose signal with the most obvious change (voltage or current in the faulted phase or the earth current). In this paper, the earth current will be further inspected.

2.2 WAVELET ANALYSIS

To locate the disturbance event in the earth current, the signal was uploaded into MATLAB Wavelet Analyzer toolbox and the decomposition of the signal was performed. As the mother wavelet, the Daubechies wavelet Db4 at decomposition level 1 was used. The reason for choosing Daubechies is a generally good experience with this type of wavelet in transient detection [1].

Figure 3 displays a wavelet transform results for a single-phase-to-ground fault occurred in time of 0,08 s. The first graph in the figure shows the original signal of the measured earth current. The second one is the approximated signal and the third is the first detail coefficient. If the level of decomposition was higher, there would be more detail coefficients that could be analyzed. However, for the purpose of this work, it proved to be enough to perform only level 1.

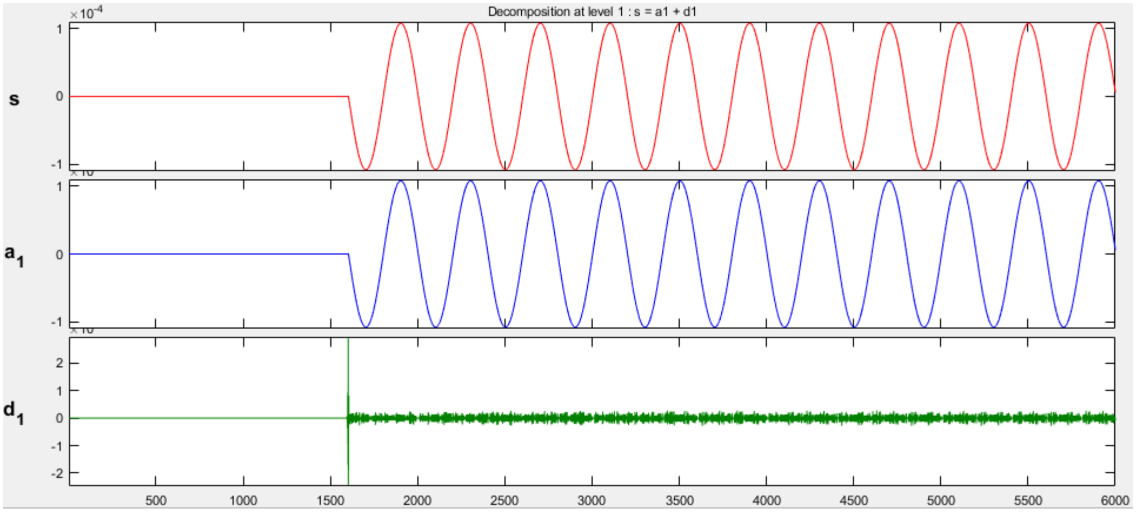

Figure 3: Signal decomposition using the Wavelet Analyzer

2.3 DETERMINATION OF THE TRANSIENT INCEPTION TIME

As seen in Figure 3, the detail coefficient reaches a local maximum at time of the fault inception. If the position of this maximum could be found (the sample order at the x-axis), the time value corresponding to this sample number could be determined.

Therefore, the detail coefficient was uploaded to MATLAB and a script has been written to find its modulus maximum. After obtaining the sample order of the modulus maximum, the matching time sample was found. This time value represents the calculated time of the fault inception.

To evaluate the time of the fault, it is possible to use different wavelets or different levels of decomposition. The principle remains the same. After performing several tests, it has been concluded that for this simple power system it is completely sufficient to use the procedure described above.

3 RESULTS

Table 2 shows results for various performed tests. When the fault was located close to the terminal with measurements, the time was calculated correctly. When the fault was situated in a bigger distance, there was an error of 0,1 ms. This inaccuracy is probably caused by the time that the travelling wave needs to get to the point of measurement. If the transient emerges in the selected point of the transmission line, a certain time is required for the travelling wave to be observed at the beginning of the line. If we assume that the propagation speed of the wave is 300 000 km/s, then to cover 30 km, time of 0,1 ms is needed. As seen in the results, due to rounding numbers, the 15 km distance is enough to cause an error in the time determination. It can be expected that a longer transmission line with more remote faults would result in bigger calculation errors.

Fault distance [km]	Actual time of the fault inception [s]	Calculated time of the fault inception [s]
5	0,1000	0,1000
5	0,2000	0,2000
10	0,0800	0,0800
10	0,1800	0,1800
15	0,1300	0,1301
15	0,2300	0,2301
20	0,0600	0,0601
20	0,1600	0,1601

Table 2: Test results

4 CONCLUSION

In this paper, a method of finding the transient inception time using wavelet transform has been discussed. The wavelet analysis becomes a very useful tool when analyzing transients. The approach described in this work proved to be successful in detecting various faults. When calculating the fault inception time, however, the travelling wave delay became evident in the wavelet analysis.

There are several methods of the fault location that utilize the correlation between the forward and the backward waves travelling along the transmission line and the detection of time of their arrival. In this case, the time delay can actually give us useful information about the travelling waves, which can be further used to precisely locate the fault. This work proved that the wavelet transform can be a suitable tool to achieve that.

In terms of the data synchronization, however, the travelling wave delay could cause troubles. In a situation when data are obtained from two terminals situated on the opposite sides of the transmission line, the fault inception time can be evaluated as identical only when the fault occurred in the same distance from both terminals. Therefore, it is advisable to process data from different measurement sites with respect to this fact.

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